Layered OCP, Unparsed Preposition, and Local Constraint Conjunction in Mandarin Tone Sandhi*

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I. Introduction

Mandarin tone sandhi, the most well-known of the Chinese sandhi phenomena, involves the change of the L[1] tone to a sandhi LH tone before another L tone. This change has been studied both under the traditional approach (i.e. Cheng (1973), Shih (1986), Hung (1987) and Zhang Z. (1988)) and the Optimality Theoretic approach (Zhang N. (1997)). In this paper it is demonstrated that these previous studies do not adequately account for Mandarin tone sandhi. The most serious problem in the derivational tradition, as pointed out in Zhang N. (1997), is its inability to offer a unified account for both the PP and the non-PP utterances in Mandarin tone sandhi. For illustration in section III, I will review Shih's (1986) work, which is one of the most well-known derivational approaches. Although Zhang N. (1997) offers an analysis in the framework of Optimality Theory (Prince and Smolensky 1993) that seems able to solve the PP/non-PP discrepancy inherited from the derivational tradition, it is shown in Section III that Zhang's analysis still admits some problems which must be resolved.

The present paper attempts to reanalyze Mandarin tone sandhi using Optimality Theory (OT). A set of tonal constraints and a set of prosodic constraints are proposed in this study. The set of tonal constraints is mainly used to account for the tonal change (i.e. the change of a L tone to a LH tone before another L tone) in Mandarin tone sandhi. This paper argues that to account for such phenomena, the set of tonal constraints must distinguish between two levels of OCP, the tonal level and the tonemic level. The prosodic constraints are posited to determine the Mandarin tone sandhi domain. This paper shows that the unparsed preposition at the prosodic word level and the Local Constraint Conjunction proposed in Smolensky (1995) play an important role in determining the tone sandhi domain for PP and non-PP tone sandhi in Mandarin. Due to limited space, I will only discuss the adagio reading in Mandarin tone sandhi.[2]

The remainder of this paper is organized as follows: Section II offers a brief introduction to the phenomenon of Mandarin tone sandhi; Section III briefly reviews two of the previous studies (Shih (1986) and Zhang N. (1997)) of Mandarin tone sandhi, focusing on some of their problems; Section IV proposes a set of tonal constraint and Section V proposes a set of prosodic constraints for Mandarin tone sandhi; and Section VI summarizes the conclusions of this study.

II. Tone Sandhi in Mandarin

Mandarin has four tones: high level (H), rising (LH), low (L) and falling (HL). In Mandarin, when two L tones are adjacent in a string, the first tone changes to a LH tone.

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* This paper has greatly benefited from discussions with Prof. Hui-chuan Huang, Prof. Jane S. Tsay, Prof. Yuchao Hsiao and Richard S. Cook. Thanks to Richard S. Cook for also helping me with my English. All errors are my own responsibility.

[1] In this paper, I follow the notation used in Shih (1986) and Hsiao (1991) to represent the Mandarin third tone as a L tone since the phonological function of Mandarin third tone is a L.

[2] Generally speaking, there are four types of readings conditioned by speech rate differences in Mandarin tone sandhi. The readings are the adagio reading, the moderate reading, the allegro reading, and the presto reading. For the discussions of these different readings in Mandarin tone sandhi, please refer to Cheng (1973) and Selkirk (1984a,b).

(1) 'umbrella'

	yu	san[3]
	rain	umbrella
base tone	L	L
sandhi tone	LH	L

In the derivational tradition, the tone sandhi rule in (2) is used to account for this tone sandh phenomenon.

(2) Mandarin Tone Sandhi Rule: L→ LH/___L

However, not every L tone followed by another L tone changes to a sandhi LH tone Consider the following trisyllabic examples:

(3)

	a. 'umbrella is good'			b. 'small umbrella'		
	yu	san	hao	xiao	yu	san
	rain	umbrella	good	small	rain	umbrella
base tone	L	L	L	L	L	L
sandhi tone	LH	LH	L	L	LH	L

To capture this phenomenon, an appropriate tone sandhi domain within which the tone sandh rule will apply must be defined. Several kinds of tone sandhi domain are proposed in th derivational tradition. For example, Shih (1986) suggests that the domain for Mandarin ton sandhi is a prosodic foot within which the Mandarin tone sandhi rule should apply cyclicall The parameter for deriving the prosodic foot in Shih (1986) will be reviewed in the next sectio By applying the tone sandhi rule in the prosodic foot, tone sandhi in the trisyllabic word string in (3) can now be explained.

(4)

	a. 'umbrella is good'			b. 'small umbrella'		
	yu	san	hao	xiao	yu	san
	rain	umbrella	good	small	rain	umbrella
base tone	((L	L)	L)	(L	(L	L))
First cycle	LH				LH	
Second cycle		LH				n.a
sandhi tone	LH	LH	L	L	LH	L

(...) = prosodic foot

III. Previous Analyses

3.1 Shih's (1986) Analysis

Shih (1986) proposes that the domain of Mandarin tone sandhi is prosodically defined ar that it is the foot that constitutes the domain of Mandarin tone sandhi. The Foot Formation Ru proposed in Shih (1986) to derive prosodic feet is given below, where the formation of the I foot should precede that of the DM foot and the super-foot.

[3] Mandarin words in this paper are represented by the Han-yu pinyin system.

(5) Foot Formation Rule (FFR) (Shih 1986: 110)

Foot (f) Construction

a. IC: Link immediate constituents into disyllabic feet.

b. DM: Scanning from left to right, string together unpaired syllables into binar feet, unless they branch to the opposite direction.

Super-foot (f') Construction

Join any leftover monosyllable to a neighboring binary foot according to th direction of syntactic branching.

The FFR successfully accounts for the domain formation of non-PP utterances like (6 However, it fails when the utterance is a quadrisyllabic string with a full NP object, as shown i (7).

(6) 'The cat walks with an umbrella.'

mao da san tzou

cat hit umbrella walk

[[ ]IC] f'

H LH LH L

(7) 'The cat is smaller than the dog.'

mao bi gou xiao

cat compare dog small

[[ ]IC] f'

?? H LH LH L

To predict the correct tonal domain, Shih suggests that FFR-IC should be skipped in these kind of word strings, and that such strings should be parsed into the DM feet directly, as shown in (8

(8) 'The cat is smaller than the dog'

mao bi gou xiao

cat compare dog small

[ ]DM [ ]DM

H L LH L

However, the claim that FFR-IC should be skipped in all and only the quadrasyllabic [P NP structures is no more than a stipulation.

Just as Shih (1986), the present analysis assumes that the tone sandhi domain of Mandari tone sandhi is a prosodic foot. However, unlike Shih's approach, the analysis in this pape provides a unified solution for tone sandhi in both PP and non-PP utterances without stipulatio

3.2 Zhang's (1997) Analysis

In order to solve the PP/non-PP problem unresolved by the derivational tradition, Zhan (1997) proposes an analysis based on OT. Zhang's (1997) approach requires two things. Th first one is a set of ranked constraints that serves to account for Mandarin tone sandhi in genera They are PTAS, *33, CI >> PTRS, Align-Di-L, Max, as listed in (9).

(9) Constraints for Mandarin Tone Sandhi (Zhang 1997)

(a) Parse UT of an Absolutely Strong Node (PTAS): The underlying tone of a stron constituent, which is not dominated by any w(eak) node, must be parsed.

(b) Parse UT of a Relatively Strong Node (PTRS): The underlying tone of a stron constituent, which is dominated by at least one w(eak) node, must be parsed.

(c) *33: No adjacent third tones are allowed.

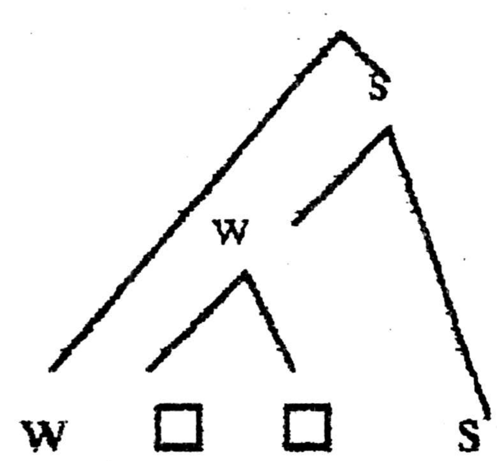
(d) Clitic Dependency (CI): A clitic cannot be separated from the tone sandhi domain of the preceding verb or preposition head.

(e) Maximal Domain (Max): The maximal tone sandhi domain is two syllables in normal speaking rate but larger in more casual or faster style.[4]

(f) Disyllabic Constituent Alignment (Align-Di-L): Align the left side of a tone sandhi domain with the left side of a disyllabic constituent when two or more tone sandhi domains occur. (disyllabic constituents are underlined in Zhang's (1997) tableaux)

The second one is the presence of the constituent strength, which serves as input to be evaluated by the constraint set. Zhang proposes that the different tonal behaviors in PP and non-PP are due to the differences of the constituent strength between the two categories. The constituent strength is a strength value assigned to every monosyllabic morpheme according to its function. To be more specific, a complement is always a phrase stress bearer. If no complement is present, then the head becomes the stress bearer. Specifiers and prehead modifiers are always weak. However, elements in PP are always unspecified, as shown in (10).

(10) 'The dog is small than the horse.'

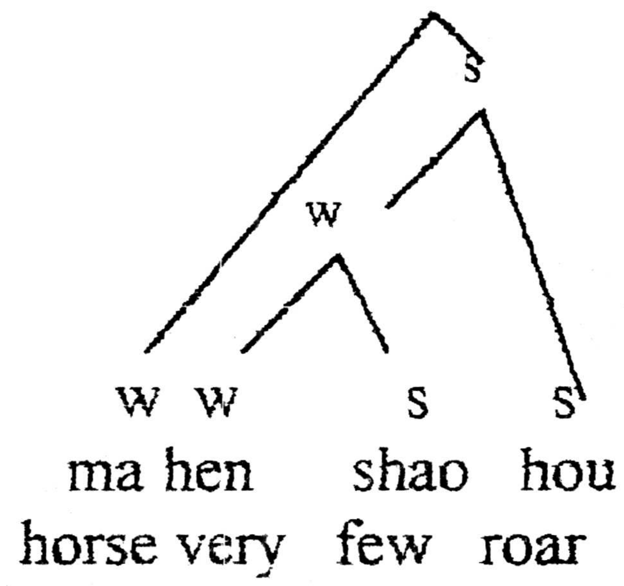


gou bi ma xiao
dog compare horse small

The unspecified constituent strength of PP can surface as either s(trong) or w(eak). Zhang assumes that a node that is dominated by all and only s nodes is categorized as absolutely strong (represented by capitalized s) and a node that is dominated by w nodes is categorized as relatively strong (represented by small s); therefore, the constituent strength of (6) should be either wwsS or wswS. Zhang claims that it is the unspecification of PP that explains why PP behaves differently from non-PP in Mandarin tone sandhi. The following two examples illustrate Zhang's point.

[4] It is assumed in Zhang (1997) that if two outputs A and B tie each other with respect to all constraints except Max, A and B have the same acceptability. They differ only in style of speaking.

(11) 'The horse seldom roars.'



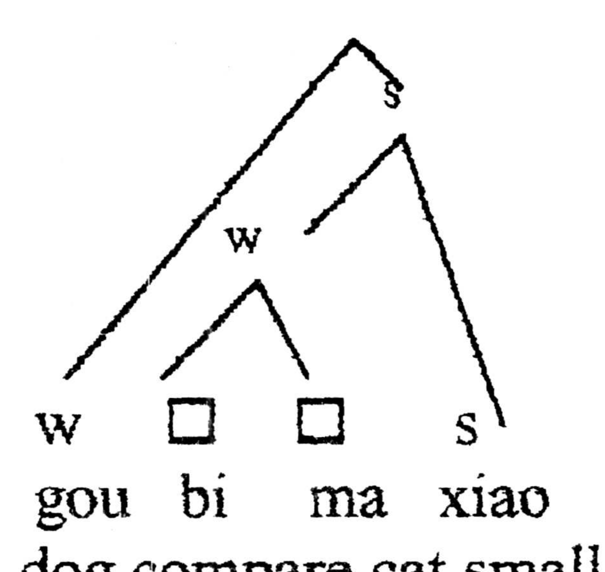
In example (11) where no PP is present, the constituent strength is wwsS. The two possible tonal outputs, candidate (c) (moderate reading) and candidate (d) (presto reading) are derived at the same time by the conflicted constraint set, as shown in (12).

(12) *ma hen shao hou* 'The horse seldom roars.'[5]

wwsS	PTAS	*33	PTRS	Align-Di-L	Max
a. (223)(3)		*!		*	*
b. (23)(22)	*!		*		
☞ c. (3)(223)			*		*
☞ d. (2223)			*		*
e. (23)(23)			*	*!	

In (12), candidate (a) violates one of the highest ranked constraints, *33, because it has two adjacent low tones. Candidate (b) also violates the highest ranked PTAS because the tone of the S node changes to a rising tone. Therefore, both candidate (a) and (b) are rejected. Candidate (c), (d) and (e) violate the PTRS constraint because the third tones of the s nodes in these three candidates all change to rising tones. However, candidate (e) violates also the Align-Di-L constraint because the disyllabic words (the second tone and the third tone) are separated; therefore, it is rejected. Candidate (c) and (d) violate the same constraint, so both are selected as optimal.

(13) 'The dog is smaller than the cat.'



In example (13), where a PP is present, the constituent strength of PP is either wwsS or wswS. If the former, the tonal output is the same as that predicted in (12). If the latter, the tonal output predicted is (23)(23), as is shown in tableau (14).

[5] The CI constraint is omitted in this tableau because it is noncrucial when the input does not contain any clitic. Likewise, it is also omitted in tableau (9).

(14) *gou bi ma xiao* 'The dog is smaller than the horse.'

wswS	PTAS	*33	PTRS	Align-Di-L	Max
a. (223)(3)		*!	*	*	*
b. (3)(223)			*		*!
c. (2223)			*		*!
☞ d. (23)(23)				*	

In (14), candidate (a) it rejected because it has adjacent low tones and that incurs violation in the undominated *33 constraint. Candidate (b), candidate (c) and candidate (d) all violate one of the constraints PTRS and Align-Di-L, which are equally ranked. Candidate (b) and candidate (c) also violate the Max constraint, thus candidate (d) is selected as the optimal output.[6]

The above shows that the unspecified constituent strength of PP opens a possibility for the (23)(23) reading to be derived in utterance with PP but not with non-PP. However, it should be noticed that Zhang's analysis of Mandarin tone sandhi has at least the following problems.

(15) Problems in Zhang (1997)

(a) The tone patterns produced with different tempos (e.g. moderate and presto) are selected as optimal candidates without differentiation.

(b) The way the presto readings are derived is inconsistent in Zhang's work. Examples are listed below:

(i) In some cases (e.g. examples (35), (39a), (39b), (45), etc. in Zhang's work), the presto readings are derived as equally optimal as the moderate readings (i.e. violate the same constraints as the moderate reading).

(ii) In some cases (e.g. examples (37) and (43) in Zhang's work), the presto readings are less optimal than the moderate readings (i.e. the presto readings violate the Max constraint but the moderate readings do not).

(iii) In one case (e.g. example (41) in Zhang's work), the presto reading will not be selected at all.

(iv) In one case (e.g. example (69) in Zhang's work), the presto reading is more optimal than the moderate reading (it violates less and lower ranked constraint than the moderate reading).

(c) It is unconvincing that Mandarin tone sandhi should completely rely on such information as phrasal stress to derive the tonal output.

(d) Zhang's analysis predicts wrong outputs. For example, Zhang proposes that the optimal candidates to the utterance, ma hen shao hou 'The horse seldom roars.' (e.g. example (35) in Zhang), is either (3)(223) (candidate (162c) here below) or (2223) (candidate (16d)), but as is shown below, the constraint set cannot rule out the unattested tone pattern (2323) (candidate (16f)).

[6] Note that according to Zhang's analysis, candidate (b) and candidate (c) are acceptable readings in a more casual or faster style since the two candidates only differ from candidate (d) in their violation of Max.

(16) *ma hen shao hou* 'The horse seldom roars.'

wwsS	PTAS	*33	PTRS	Align-Di-L	Max
a. (223)(3)		*!		*	*
b. (23)(22)	*!		*		
☞ c. (3)(223)			*		*
☞ d. (2223)			*		*
e. (23)(23)			*	*!	
*☞ f. (2323)			*		*

Though candidate (f) has exactly the same tonal pattern as candidate (e), unlike candidate (e), candidate (f) does not violate the Align-Di-L constraint. That is because the Align-Di-L constraint requires that the left side of a tone sandhi domain should be aligned with the left side of a disyllabic constituent only when two or more tone sandhi domains occur. Candidate (f) has only one domain; therefore, it does not incur any violation in the Align-Di-L constraint. Consequently, candidate (f) would violate exactly the same constraints as candidate (c) and candidate (d) will be wrongly selected as equally optimal as candidate (c) and candidate (d).

IV. The Tonal Constraints

This section starts the analysis of this paper. A set of tonal constraints is proposed to account for the tonal behavior of Mandarin. Within this section, the tone sandhi domain is included in the input in the OT tableaux for ease of discussion. I will discuss how the domain is predicted by a set of prosodic constraints in the next section.

Recall that Mandarin tone sandhi is related to the phenomenon that when *two L tones* are adjacent in a string, the *first* changes to a sandhi tone. This phenomenon can be captured by the following two constraints.

(17) OCP-L: Adjacent low tones are prohibited.
(18) Ident-FT: The final tone of the outmost foot is identical to its input correspondent.

The OCP-L constraint is motivated by the universal Obligatory Contour Principle that prohibits adjacent identical elements (Leben 1973; Goldsmith 1976). This constraint explains why adjacent Mandarin L tones (within a tonal domain) often need to undergo some tonal alternations. The Ident-FT constraint belongs to one of the Positional Faithfulness constraints proposed in Beckman (1998) which is inspired by the Parse(F) constraints of Selkirk (1994). The Positional Faithfulness constraints state that "correspondent segments in a privileged position must have identical specification for [F]." Since Mandarin, like Min and some Southern Wu dialects, belongs to a right-dominant system which tends to maintain the identity of the rightmost tone (of words or even prosodic domains), while allowing tones to change on the non-final tones in sandhi contexts (Chen 1996),[7] I, therefore, propose the Ident-FT constraint to ensure that when two Mandarin L tones are adjacent, it is always the tone on the left edge, but not on the right edge that undergoes tonal changes. The Ident-FT constraint is sometimes in conflict with the OCP-L constraint. (19) shows that it must outrank the OCP-L constraint to predict the attested output.[8]

[7] Please refer also to Qian (1992), and Duanmu (1993) for the discussion of characterizing the prosodic systems of Chinese dialects into right or left prominent.
[8] Note that candidate (19b) is the attested output in the moderate reading, but it is not in the adagio reading.

(19) 'I ordered fried noodles' Ranking: Ident-FT >> OCP-L

Wo dian chao mian (L L) (L HL)	Ident-FT	OCP-L
☞ a. LH L L HL		*
b. LH LH L HL	*!	

It should be noticed that these two constraints are not enough. Since it cannot reject the unattested output (LH L)(LH HL) for the input in tableau (19) above. (LH L)(LH HL) will be chosen before the attested output (19a) as it satisfies both Ident-FT and OCP-L. The following faithfulness constraint is needed.

(20) Ident-L*L: Input-Output correspondent L*L tone sequence are identical.

Tableau (21) illustrates how the Ident-L*L constraint, when given the undominated status in the ranking, works to reject the unattested output of (LH L)(LH HL), i.e. (21c).

(21) 'I ordered fried noodles' Ranking: Ident-FT, Ident-L*L >> OCP-L

Wo dian chao mian (L L) (L HL)	Ident-FT	Ident-L*L	OCP-L
☞ a. LH L L HL			*
b. LH LH L HL	*!		
c. LH L LH HL		*!	

4.1 Layered OCP

Up to now, three ranked constraints have been proposed to explain why a non-final L tone in Mandarin undergoes tonal change when followed by another L tone within the tonal domain. However, no constraints have yet been suggested to explain why the tone that undergoes tonal alternation changes to a LH tone but not to other Mandarin tones like H and HL.[9] The possibility for a L tone to change to a H tone can be very easily ruled out by positing the Ident[+low] constraint in (22) which bans any input tones from loosing the [+low] features, if any, in their corresponding output tones.

(22) Ident[+low]: Correspondent tones are identical in feature [+low].

How about the choice between the LH tone and the HL tone which both contain the [+low] feature. Thanks to the high ranking of the Ident-FT constraint, only the following two candidates in (23) are the possible output candidates for an input with two L tones, where only (23a) is the attested output.

(23) Input: L L
Output: a. LH L
b. HL L

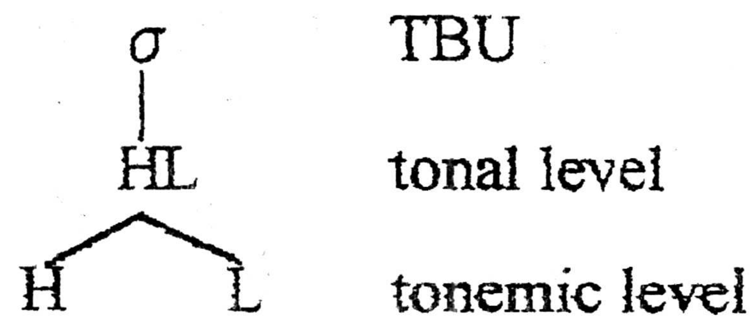
A solution must be found to ensure that (23a) is selected and (23b) is rejected. In the following paragraphs, I will show that the solution lies in the re-evaluation of the OCP-L constraint, with respect to different levels of OCP.

Let us begin with the issue of the tonology of the contour tones in Mandarin. It is often

[9] I am grateful to Prof. Jane S. Tsay for leading me to this issue and to Prof. Hui-chuan Huang for her helpful comments.

proposed that the contour tones of Chinese are a unit grouped under a single tonal node. (Yip (1989) and Bao (1990)) In Chinese, the tone-bearing unit (TBU) is the syllable; therefore, a contour HL tone in Mandarin is represented as follows:

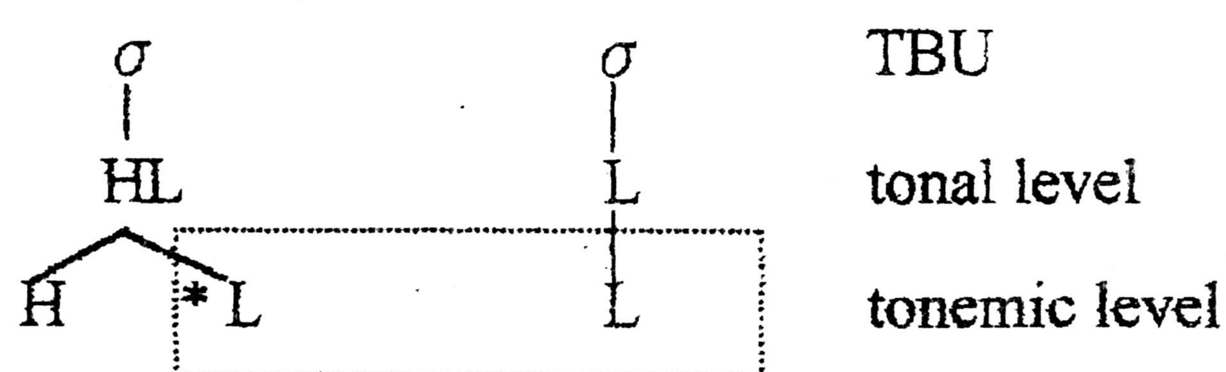
(24)



As shown in (24), the contour tone HL is composed of two level tones, H and L, in the tonemic level. The two level tonemes are conjoined in the tonal level to form the contour HL tone. Therefore, the contour tone is associated to the TBU as a single unit.

Based on this tonology, why (23a) is chosen and (23b) rejected becomes clear. The reason (23b) should be rejected is owing to the fact that (23b), but not (23a), violates the OCP-L constraint in the tonemic level, as shown in (25).

(25)



The definition of the OCP-L constraint in (17) can be modified a bit as follows to emphasize this point:

(26) OCP-L: At the tonimic level, adjacent L tones are prohibited.

This constraint can rule out the output candidates HL L and L L generated from the input L L because both output candidates contain adjacent L tones in the tonemic level. But is it appropriate to count on this constraint to derive the tonal outputs in Mandarin tone sandhi? The answer is no, as it could at the same time rule out the attested output candidate HL L for the input HL L. Thought this kind of wrong prediction might be resolved by ranking a constraint requiring input-output tonal identity, such as the IO-IdentT in (27), above the OCP-L constraint, as shown in (28), the same solution would predict the wrong output for an input with a sequence L tones, as illustrated in (29). That is because by ranking the IO-IdentT constraint above the OCP-L constraint, the optimal candidate predicted would always be the one that does not undergo any tonal changes.

(27) IO-IdentT: Input-Output correspondent tones are identical.

(28) 'change rice'

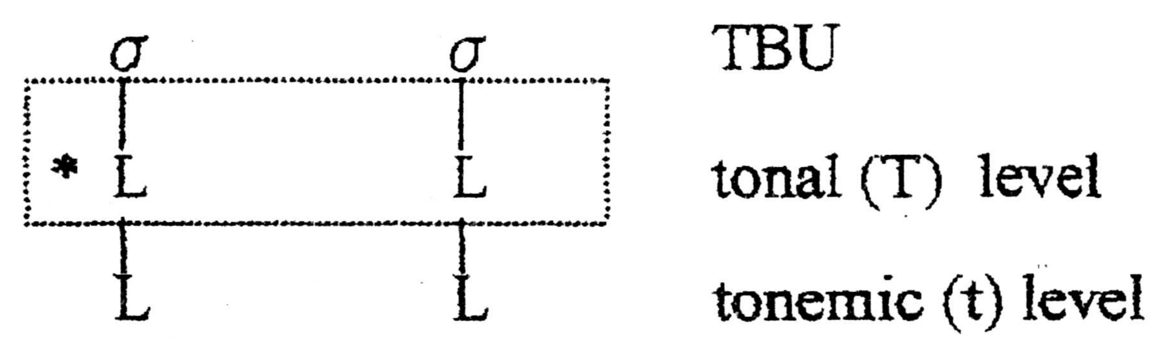
huan mi (HL L)	IO-IdentT	OCP-L
☞a. HL L		*
b. LH L	*!	

(29) 'buy rice'

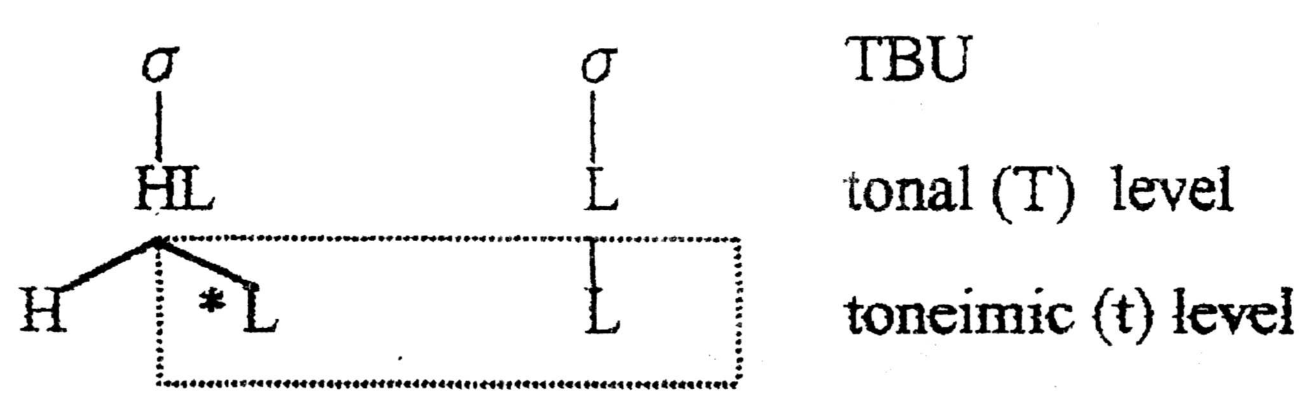
	mai mi (L L)	IO-IdentT	OCP-L
☞	a. LH L	*!	
	☞b. L L		*
	c. H L L	*!	

To solve this ranking paradox, I propose that the OCP-L constraint should be split to distinguish between two different levels, the tonal level and the tonemic level.[10]

(30) OCP-L(T): At the tone (T) level, adjacent L tones are prohibited.



(31) OCP-L(t): At the tonimic (t) level, adjacent L tones are prohibited.



The OCP-L(T) constraint should outrank the IO-IdentT constraint to reject the wrong prediction in (29) and the OCP-L(t) constraint should be outranked by the IO-IdentT constraint to preserve the correct prediction in (28). To sum up, the constraint ranking for the present tonal constraints is:

(32) Ident [+low], Ident-FT, Ident L*L >> OCP-L(T) >> IO-IdentT >> OCP-L(t)

Finally, I would like to discuss how the attested readings for word strings with recursive foot structures such as ((L L) L) are predicted. In OT, phonological phenomena that involve cyclic applications of rules in the derivational tradition are replaced by the O-O (output-output) correspondence constraint in the works of many linguists such as Kenstowicz (1996), Ito, Kitagawa, & Mester (1996), Ito & Mester (1998), and Duanmu (1997). Tone sandhi in Mandarin with recursive foot structures also needs to be resorted to the O-O correspondence constraint (McCarthy and Prince 1995).[11] The following tableau shows how the attested reading (33b) fails to be predicted by the current constraint set in (32).

[10] The proposal is reasonable since just as tonal spreading rules can act on either the tonal level or the tonimic level, the OCP constraint should in principle act on both levels. (Selkirk 1989: 163)

[11] I would like to thank Prof. Yuchao Hsiao for pointing out the role of the O-O correspondence constraint in Mandarin tone sandhi.

(33) ‘presidential hall’

zong tong fu L L L ((σ σ) σ)	Ident[+low]	Ident-FT	Ident-L*L	OCP-L(T)	IO-IdentT	OCP-L(t)
a. LH L L				*!	*	*
☞ b. LH LH L					**!	
☞c. L LH L					*	*
d. L L L				*!*		**
e. LH L LH		*!			**	*
f. H L L	*!			*	*	*

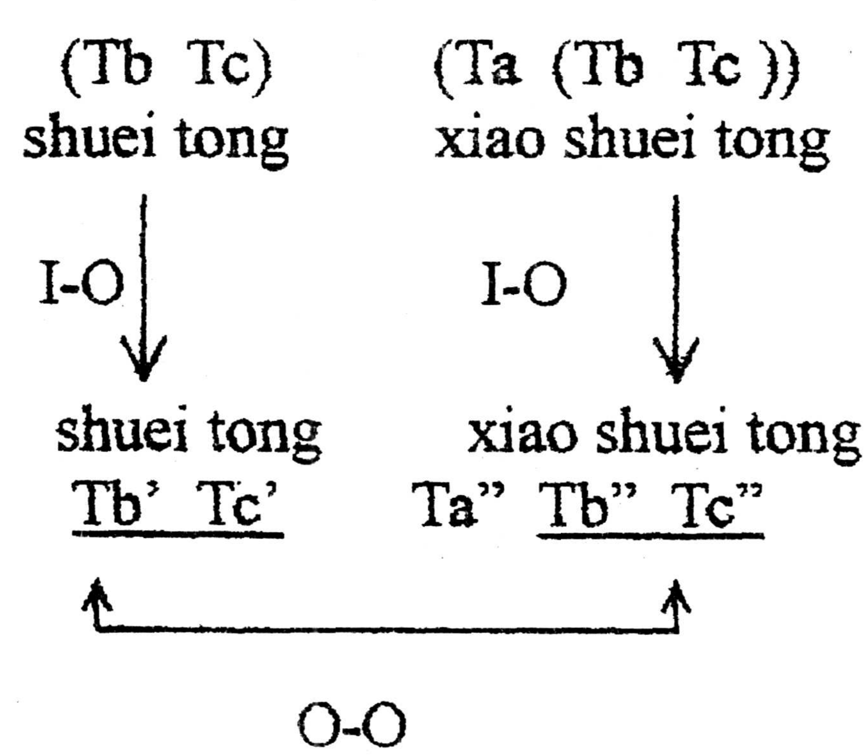
In (33), candidate (c), rather than candidate (b), is selected as the optimal output. (c) is selecte as the optimal output because it incurs less violation than (b) does in the IO-IdentT constraint.

To avoid the wrong prediction in (33), the following correspondence constraint is propose here.

(34) OO-IdentT：The tones in a bound form of foot is identical to those in their correspondin free form.

The OO-IdentT constraint requires that the tones of a foot embedded within a construction (e.g Tb" and Tc" in (35)) must be identical to those tones of a foot appeared as an independent foo (e.g. Tb' and Tc' in (35)).

(35)



The OO-IdentT constraint must outrank the IO-IdentT constraint to rule out (33c) above. I addition, since the OO-IdentT constraint is sometimes violated to prevent the violation o OCP-L(T) (as will be seen below in (37)) it should be ranked lower than the OCP-L(T) constrain The ranking of the final tonal constraints is summarized below:

(36) Ident[+low], Ident-FT, Ident L*L >> OCP-L(T) >> OO-IdentT >> IO-IdentT>> OCP-L(t)

Tableau (37) shows how the OO-IdentT constraint functions to rule out the unattested outpu (37c) and correctly predict (37b) as the optimal output. The inactive Ident L*L constraint i omitted in the tableau for simplification.

(37) 'presidential hall' Reference tonal output: (zongLH tongL)[12]

((zong tong) fu) L L L	Ident[+low]	Ident-FT	OCP-L(T)	OO-IdentT	IO-IdentT	OCP-L(
a. LH L L			*!		*	*
☞ b. LH LH L				*	**	
c. L LH L				**!	*	*
d. L L L			*!*	*		**
e. LH L LH		*!			**	*
f. H L L	*!		*	*	*	*

In (37), the unattested output *zong*L *tong*LH *fu*L (i.e. (37c)) can be successfully ruled ou because it incurs more violations in the OO-IdentT constraint than the attested output *zong*Ll *tong*LH *fu*L (i.e. (37b) since both tones of *zong* and *tong* in (c) are not identical to those in the: corresponding free form (i.e. the reference tonal output above the tableau) while in (b), only th tone of *tong* is not identical to its corresponding tone in the reference tonal output.

V. The Prosodic Constraints

This section presents a set of ranked prosodic constraints to derive the tone sandhi domain for both the PP and the non-PP utterances. In section 5.1, a set of prosodic constraints is posite based on the non-PP utterances. Then, the constraints proposed are tested against the P utterances in section 5.2, where I will show that the unparsed nature of Prep. and a constrain based on the Local Constraint Conjoin play important roles in determining the tone sandl domain in Mandarin.

5.1 The Non-PP Utterances

Like other languages, the best foot structure in Mandarin is disyllabic. This fact can b captured and maintained by the FtBin constraint listed in (38).

(38) FtBin: Foot must be binary under syllabic analysis.

In even-numbered syllables, the best foot structure that satisfies the FtBin constraint would b (σ σ)(σ σ). However, in odd-numbered syllables, the best foot structure that satisfies th FtBin constraint would be a structure with an unparsed syllable such as(σ σ) σ . To prevent th unparsed structure from being chosen, a constraint that requires that every syllable in the inpu should be parsed into feet is needed.

(39) ParseSyll：Parse syllables into feet.

The ParseSyll constraint requires that every syllable must be parsed into foot. When it outrank FtBin, candidates that contain unparsed syllables (e.g. σ (σ σ)) can be rejected naturall However, with only these two constraints, unattested domain outputs formed with monosyllab feet (e.g. (σ)(σ σ)) will be wrongly selected as the optimal output on par with the atteste

[12] The tones of *zong tong* 'president' appeared in a free form can be derived by the following tableau.

(zong tong) L L	Ident[+low]	Ident-FT	OCP-L(T)	OO-IdentT	IO-IdentT	OCP-L(t)
a. LH LH		*!			**	
☞b. LH L					*	
c. L LH		*!			*	*
d. L L			*!			*

domain outputs (σ (σ σ)) as shown in (40), since both of them satisfy the ParseSyll constraint and violate the FtBin constraint once.

(40)

	σ σ σ	ParseSyll	FtBin
☞	☞ a.(σ (σ σ))		*
	☞ b.(σ) (σ σ)		*
	c. σ (σ σ)	*!	

To get rid of (b), the following constraint is needed.

(41) *MonoF: Avoid monosyllabic feet.

Monosyllabic foot is a marked structure. In Mandarin tone sandhi, while feet can sometimes be polysyllabic (i.e. more than two syllables); normally, they are never monosyllabic. In other words, monosyllabic feet are more marked than polysyllabic feet in Mandarin; therefore, the *MonoF constraint is needed in addition to the FtBin constraint. Moreover, the *MonoF constraint should have a more dominant status than the FtBin constraint (i.e. *MonoF >> FtBin). Since *MonoF is not in conflict with ParseSyll, it is placed at the same rank with the ParseSyll constraint. Consequently, the ranking for the present prosodic constraints is :

(42) ParseSyll, *MonoF >> FtBin

Notice, however, that the ranking in (42) is still far from sufficient, as it could only make predictions about how many syllables a Mandarin prosodic foot should contain but not about how the foot should be formed. For instance, it could not make decisions between the foot structures (σ (σ σ)) and ((σ σ) σ) among trisyllabic word strings, as shown in (43):

(43)

σ σ σ	ParseSyll	*MonoF	FtBin
☞a.((σ σ) σ)			☞ *
☞b.(σ (σ σ))			*
c.(σ) (σ σ)		*!	*
d. σ (σ σ)	*!		

How should the decision be made? Since Selkirk (1986), it is often agreed that prosodic structures of a language are sensitive, though not necessarily isomorphic, to that language's syntactic structure (Shih 1986, Hsiao 1991, 1995, etc.) In the derivational tradition, the End-based Theory (Selkirk 1986) is proposed to account for the relation between the prosodic and the syntactic structures, where the prosodic structures are posited to be defined in terms of the right or left ends of syntactic constituents of designate types. In OT, the edge sharing phenomena between syntactic and prosodic structures are captured by the family of Generalized Alignment constraint proposed in McCarthy and Prince (1993).

(44) Generalized Alignment (McCarthy & Prince 1993: 80)

Align (Cat1, Edge1, Cat, Edge 2) = def
∀ Cat1 ∃ Cat2 such that Edge 1 of Cat1 and Edge2 of Cat2 coincide.
Where Cat1, Cat2 ∈ PCat U GCat
Edge1, Edge2 {Right, Left}

The Generalized Alignment constraint is based on the End-based Theory but is extended to account for the edge sharing phenomena of all kinds of grammatical categories, including morphological as well as syntactic categories, and all kinds of prosodic categories, including the word-internal prosodic categories such as syllables, feet, and features.

In Mandarin, the foot formation is also sensitive to the syntactic structure, in particular, the immediate constituent (IC)[13] of a sentence (Shih 1986). To predict the foot formation in Mandarin, I proposed the following alignment constraint.

(45) The AlignIC/Ft Constraint (AlignIC/Ft)

a. Align(IC, Ft)L: The left edge of every immediate constituent (IC) is aligned with the left edge of some foot (Ft).
b. Align(IC, Ft)R: The right edge of every immediate constituent (IC) is aligned with the right edge of some foot (Ft).

The AlignIC/Ft constraint requires that the left and the right edges of every IC must be aligned with the left and the right edges of a foot. This constraint can now make decision between the output foot structures (σ (σ σ)) and ((σ σ) σ) generated from trisyllabic inputs. The AlignIC/Ft constraint would select (σ (σ σ)), but not ((σ σ) σ), as the optimal foot structure if the syntactic structure of the input is { σ { σ σ }}, where {...} stands for immediate constituent (IC), because the left edge of the second syllable in the latter foot structure which is an IC boundary is not left aligned with a foot boundary. It should be noted, however, that it is not always true that the left and the right edges of every IC are always aligned with the left and the right edges of a foot in the attested output . For instance, for quadrasyllabic input with recursive IC structures like {*xiang*{*mai*{*shuei tong*}}} 'want to buy water pail', the attested foot domain is always not the one that obeys the AlignIC/Ft constraint, namely (*xiang*(*mai*(*shuei tong*))), but is the one that has the structure (*xiang mai*)(*shuei tong*), unless the string is a single lexical word that will be discussed later in (46), (47) and (48). Obviously, the selection of (σ σ)(σ σ) before (σ (σ (σ σ))) for the input { σ { σ { σ σ }}} is to minimize the violations in the FtBin constraint, even though the AlignIC/Ft constraint would be sacrifices a bit. In other words, the FtBin constraint is satisfied at cost of the AlignIC/Ft constraint. Therefore, the FtBin constraint should outrank the AlignIC/Ft constraint. Namely FtBin >> Align IC/Ft.

In the preceding passage, I have shown that the FtBin constraint should outrank the AlignIC/Ft constraint to predict the correct tonal domain for Mandarin tone sandhi. However, there seem to be some cases that show that the AlignIC/Ft constraint should instead outrank the FtBin constraint. Compare A column with B column in (46).

[13] The immediate constituents of A will be the nodes which are immediately dominated by A. (Radford 1988)

(46)

(A) FtBin >> Align IC/Ft	(B) AlignIC/Ft >> FtBin
xiang mai shuei tong want buy water pail {σ {σ {σ σ}}} (σ σ)(σ σ)	ruan gou bing gan soft dog biscuit {σ {σ{σ σ}}} (σ (σ(σ σ)))
na zhong jiou hao which kind wine good {{{σ σ} σ} σ} (σ σ)(σ σ)	fu dao zhang qi proctor open {{{σ σ} σ} σ} (((σ σ) σ) σ)

The examples in column A and column B have exactly the same immediate constituencies, but surprisingly, the attested foot structures for them are completely different. Therefore, it is clear that a constraint ranking that could predict the outputs for column A would certainly fail to predict the outputs for column B. To derive the foot structures in column A, where the AlignIC/Ft constraint is sacrificed to satisfy the FtBin constraint, the AlignIC/Ft constraint cannot outrank the FtBin constraint. On the contrary, to derive the foot structures in column B, where the FtBin constraint is sacrificed to satisfy the AlignIC/Ft constraint, the AlignIC/Ft constraint must outrank the FtBin constraint. The examples above seem to present a ranking paradox between the FtBin constraint and the AlignIC/Ft constraint. However, by having a closer examination of the above examples, we can notice that despite the fact that the examples in the two columns have the same IC structures, they have very different prosodic word structures. The prosodic word in Mandarin is defined here as equal to a lexical word (e.g. Noun, Verb, Adjective, etc). The functional categories (e.g. Prep. classifier, pronoun, etc.) do not constitute prosodic words. For example, in the string, *ma bi gou xiao* 'the horse is smaller than the dog', *ma*, *gou* and *xiao* are lexical categories and form prosodic words respectively. The word *bi* is a function word, and therefore does not form a prosodic word. The prosodic structure for the string is thus [[*ma*] *bi* [*gou*][*xiao*]. ("[" and "]" stand for the left and right edges of a prosodic word respectively).[14] (47) and (48) illustrate the differences between the prosodic word structures of the examples in (46A) and (46B).

[14] In OT, this can be captured by positing the following two constraints. However, for ease of discussion, it is omitted in this paper.

(1) AlignLex/Prwd Constraint (= (WdCon) Selkirk 1995)

a. Align(Lex, Prwd)L: The left edge of every Lexical word (Lex) is aligned with the left edge of some Prosodic word (Prwd).

b. Align(Lex Prwd)R: The right edge of every Lexical word (Lex) is aligned with the right edge of some Prosodic word (Prwd).

(2) Align Prwd/Lex Constraint (= (PwdCon) Selkirk 1995)

a. Align(Prwd, Lex)L: The left edge of every Prosodic word (Prwd) is aligned with the left edge of some Lexical word (Lex).

b. Align(Prwd, Lex)R: The right edge of every Prosodic word (Prwd)is aligned with the right edge of some Lexical word (Lex).

(47)

	xiang mai shuei tong want buy water pail	ruan gou bing gan soft dog biscuit
Immediate Constituency	{σ {σ {σ σ}}}	{σ {σ {σ σ}}}
Prosodic Word Structure	[σ] [σ] [σ σ]	[σ [σ [σ σ]]] [15]
Prosodic Foot Structure	(σ σ) (σ σ)	(σ (σ (σ σ)))

(48)

	na zhong jiou hao which kind wine good	fu dao zhang qi proctor open
Immediate Constituency	{{{σ σ} σ} σ}	{{{σ σ} σ} σ}
Prosodic Word Structure	[σ σ] [σ] [σ]	[[σ σ] σ] [σ]
Prosodic Foot Structure	(σ σ) (σ σ)	(((σ σ) σ) σ)

The problem of why the examples in columns A and B have exactly the same IC structures but have completely different foot structures becomes explicable. The reason why the foot structures for column B should not be (σ σ)(σ σ) is that it would break the prosodic word into two pieces. Take (49) for illustration:

(49) 'for Mr. Proctor'

```
[( σ  σ )] ( σ]   [σ]))
  fu dao   zhang   qi
     proctor       open
```

To avoid breaking a single prosodic word into pieces, we can resort to the following alignment constraint that requires the left and the right edges of every foot to be aligned with the corresponding edges of a prosodic word. The AlignFt/Prwd constraint should outrank the FtBin constraint.

[15] Following Ito & Mester (1998:36), I refer to the terminal elements in the tree diagrams of compounds or words consisting of complex morphological objects as stems and the non-terminal elements as (syntactic) words. For example, the word internal structures of the complex word *ruan gou bing gan* is <*ruan* <*gou* <*bing gan*> > > ("<" and ">" stand for the left and right edges of a word respectively) as depicted below.

```
   word
    /  \
   /     word
  /    /   \
 /    /      word
/    /     /    \
stem  stem   stem   stem
ruan  gou    bing   gan
   'soft dog biscuit'
```

Therefore, the prosodic structure of the string is [*ruan*[*gou*[*bing gan*]]] 。

(50) The AlignFt/Prwd Constraint (AlignFt/Prwd)

a. Align(Ft, Prwd)L: The left edge of every foot (Ft) is aligned with the left edge of some Prosodic word (Prwd).

b. Align(Ft, Prwd)R: The right edge of every foot (Ft) is aligned with the right edge of some Prosodic word (Prwd).

The AlignFt/Prwd is sometimes in conflict with ParseSyll, as can be seen below in (62a) below where the AlignFt/Prwd constraint is violated to satisfy the ParseSyll constraint; therefore, the ranking proposed for the prosodic constraints of the present analysis is:

(51) ParseSyll, *MonoF >> AlignFt/Prwd, >> FtBin >> AlignIC/Ft

The following tableau shows how the constraints in (51) function to predict the domain output for Mandarin tone sandhi.

(52) 'to Mr. proctor'

[fu dao] zhang] [qi] proctor open {{{σ σ} σ} σ}	ParseSyll	*MonoF	AlignFt/Prwd L	AlignFt/Prwd R	FtBin	AlignIC/Ft L	AlignIC/Ft R
☞a. (((σ σ) σ) σ)					***		
b. (σ σ)(σ σ)			*!				*

5.2 The PP Utterances, the unparsed Prep. and Local Constraint Conjunction

In this section, the prosodic constraints set proposed based on the non-PP utterances is tested against the PP utterances to see how it works to predict the domain for the PP utterances in Mandarin tone sandhi. Let us begin with the example unresolved by the FFR in Shih (1986), namely, the quadrasyllabic [P NP] string in (7), and compare it with the non-PP example in (8). Tableau (53) and (54) show that the constraint set in (51) can correctly account for both examples.

(53) 'The horse is smaller than the dog.' (with PP)

[[ma] bi [gou][xiao] {σ {{σ σ }σ}}	ParseSyll	*MonoF	AlignFt/Prwd L	AlignFt/Prwd R	FtBin	AlignIC/Ft L	AlignIC/Ft R
a. (σ (σ σ) σ)			*!		**		
☞b.(σ σ) (σ σ)				*		*	*
c.(σ (σ (σ σ)))			*!		***		*
d.(((σ σ) σ) σ)				*	*!**	*	

(54) 'The dog walks with an umbrella.' (without PP)

[gou] [da sang] [zou] dog hit umbrella walk {σ {σ σ} σ}	ParseSyll	*MonoF	AlignFt/Prwd L	AlignFt/Prwd R	FtBin	AlignIC/Ft L	AlignIC/Ft R
☞a.(σ (σ σ) σ)					**		
b.(σ σ)(σ σ)			*!	*		*	*

The reason why (σ σ)(σ σ) in (54) cannot be selected is because it will break the prosodic word [*da sang*] into pieces and violate the undominated AlignFt/Prwd constraint. The selectionof the structure (σ σ)(σ σ) will also cause a violation in the AlignFt/Prwd constraint in the PP utterance in (53), but that is all right. That is because the preposition *bi* does not form a prosodic word. Therefore, placing a foot boundary at either edges of it would result in a violation in the AlignFt/Prwd constraint. As a result, the violations in the AlignFt/Prwd constraint become non-crucial in word strings that contain PP, as exemplified in (53). Consequently, the optimal candidate selected will be the one that satisfy the FtBin constraint most, i.e. (σ σ)(σ σ). In other word, it is because that the preposition is unparsed in the prosodic word level that has made the discrepancy between the PP and the non-PP utterances with the same IC structures unaccountable by the derivational tradition become explainable. However, it must be noted that it is also due to the unparsed preposition in the prosodic word level that would make the present constraints set fail to rule out the flat structure in (55b). That is because the flat structures always satisfy ParseSyll and *MonoF and often skip AlignFt/Prwd violations which are inescapable in the attested output of the PP utterances.

(55) 'The horse is smaller than the dog.'

	[[ma] bi [gou][xiao]] {σ {{σ σ }σ}}	*MonoF	ParseSyll	AlignFt/Prwd		FtBin	AlignIC/Ft	
				L	R		L	R
☞	a. (σ σ) (σ σ)				*!		*	*
	☞b.(σ σ σ σ)					**	*	*

In order to prevent the flat structures from being wrongly selected as the optimal candidates, we need to resort to the Local Constraint Conjunction:

(56) Local Conjunction (Smolensky 1995, Alderete 1997, Ito & Mester 1998, Morris 2000).
The local conjunction of C1 and C2 in domain D, C1 &C2, is violated when there is some domain of type D in which both C1 and C2 are violated.

The Local Constraint Conjunction posits that two constraint violations are worse when they occur in the same location. In other words, a single violation of the conjoined constraint C1 & C2 is much worse than 2 violations of a non-conjoined constraint C1 or C2. Consequently, Smolensky (1995) points out that universally, the conjoined constraint C1 & C2 will always outrank the independent non-conjoined constraints C1, C2, namely, C1 & C2 >> C1, C2.

In Mandarin, the FtBin constraint and the AlignIC/Ft constraint both play the central roles in determining the tone sandhi domain. In Mandarin tone sandhi, the attested domain outputs would either violate the AlignIC/Ft constraint to satisfy the FtBin constraint, as in the examples in (46A) and (53), or violate the FtBin constraint to satisfy the AlignIC/Ft constraint, as exemplified in (46B), but never violate both of them at the same time. However, quite on the contrary, unattested flat domain outputs always violate both the FtBin constraint and the AlignIC/Ft constraint as exemplified in (55).[16] Therefore, I propose a constraint conjoining the FtBin constraint and the AlignIC/Ft constraint and place it above the FtBin constraint.

(57) FtBin & AlignIC/Ft: This constraint is violated when both the FtBin constraint and the AlignIC/Ft constraint are violated.

Since the unattested flat structures always violate both the FtBin and the AlignIC/Ft constraint, it

---

[16] Note that the attested foot structure for disyllabic input is flat and it violated neither the FtBin constraint nor the AlignIC/Ft constraint. However, since in this case, the flat output is the attested output, it is out of the question here.

can be rejected successfully by the undominated FtBin & AlignIC/Ft constraint, as shown in (58).

'The horse is smaller than the dog.'

[ma] bi [gou][xiao] {σ{{σ σ}σ}}	*MonoF	Parse Syll	FtBin & AlignIC/Ft	AlignFt/Prwd		FtBin	AlignIC
				L	R		L
☞a.(σ σ)(σ σ)					*		*
b.(σ σ σ σ)			*			*!*	*

And since all the attested outputs will not violate both FtBin and AlignIC/Ft at the same time, the conjoined constraint in (56) will not influence them. Therefore, the final prosodic constraints proposed to account for both the PP and the non-PP utterances are:

(59) ParseSyll, *MonoF >> FtBin & AlignIC/Ft, AlignFt/Prwd >> FtBin >> AlignIC/Ft

More PP examples are tested below to confirm the function of the constraint set in (59).

(60) 'smaller than dog'

bi [gou][xiao] {{σ σ}σ}	*MonoF	Parse Syll	FtBin & AlignIC/Ft	AlignFt/Prwd		FtBin	AlignIC/	
				L	R		L	F
a. (σ (σ σ))			÷	÷!		÷		÷
☞ b.((σ σ) σ)				*		*		
c. (σ σ σ)			*	*!		*		*

(61) 'The horse is more timid than the dog.'

[ma] bi [gou][dan-xiao] {σ{σ σ}{σ σ}}	*MonoF	Parse Syll	FtBin & AlignIC/Ft	A(Ft, Prwd)		FtBin	A(IC, F	
				L	R		L	F
☞a. (σ (σ σ))(σ σ)				*		*		
b. ((σ σ) σ)(σ σ)			*		*!	*	*	
c. (σ σ σ σ σ)			*			**!*	**	*
d.(((σ σ) σ) σ)σ)			*		*!	***	**	

(62) 'The little horse is bigger than the dog'

[xiao ma] bi [gou] [da] {{σ σ}{{σ σ}σ}}	*MonoF	Parse Syll	FtBin & AlignIC/Ft	AlignFt/Prwd		FtBin	Align
				L	R		L
☞a. (σ σ)((σ σ) σ)				*		*	
b. ((σ σ) σ)(σ σ)			*		*!	*	*!
c. (σ σ σ σ σ)			*			**!*	*
d.(((σ σ) σ) σ) σ)			*		*!	***	*
e. (σ σ) σ (σ σ)		*!					*

VI. Conclusion

Within the framework of OT, this paper has regulated 7 tonal constraints and 6 prosodic constraints for Mandarin tone sandhi. The two sets of constraints are summarized below:

- The tonal constraints set:
  Ident[+low], Ident-FT, IdentL*L >> OCP-L(T) >> OO-IdentT >> IO-IdentT >> OCP-L(t)

- The prosodic constraints set:
  ParseSyll, *MonoF >> FtBin & AlignIC/Ft, AlignFt/Prwd >> FtBin >>AlignIC/Ft

The tonal constraints are proposed to account for the tonal changes in Mandarin, where I have shown that the OCP-L constraint needs to be divided into two sub-constraints, the OCP-L(T) constrain that is active at the tonal level, and the OCP-L(t) constraint that is active at the tonemic level.

Failing to define tone sandhi domains that could account for tone sandhi in both the PP and the non-PP utterances in Mandarin is a common problem left by the derivational tradition. The prosodic constraints are proposed in this study to resolve this problem. With the help of the unparsed nature of the prepositions in the prosodic word level and the Local Constraint Conjunction, tone sandhi domains for both the PP and the non-PP utterances are shown to be derived naturally by the same set of prosodic constraints without any additional stipulation.

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